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# A temperature-survey in the secondary air mixing zone of the burner of a J33-A-17 turbo jet engine.

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A TEMPERATURE SURVEY IN THE SECONDARY AIR MIXING ZONE OF THE BURNER OF A J33-A-17 TURBO JET ENGINE

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## SUMMARY

This investigation was conducted to obtain information on the mixing and mixing rates of the secondary air with the gases of combustion in a jet engine burner. For this purpose a J33-A-17 Turbo Jet Engine, can type, burner was utilized.

It was found, for the range of fuel-air ratios investigated, .009 and .012, that mixing was accomplished in a fairly uniform and definite manner. Increasing fuel-air ratio increased the temperatures near the center where the hot core of the gases maintained itself. As the amount of secondary air into the flame tube increased, at a constant fuel-air ratio, the higher temperature gases near the center would be cooled and the gases previously cooled near the boundaries of the flame tube remained practically constant in temperature. Thus a very high temperature gradient that existed near the fuel nozzle would be gradually decreased. However, near the end of the burner, where secondary air ceased to be admitted, a temperature gradient still remained indicating that improvement can be made to produce uniform temperature distribution.

Low temperatures adjacent to the flame tube were observed in all cases and were within the structural temperature

limitations. The secondary air between the flame tube and outer liner was practically constant at 185-195° F.

## INTRODUCTION

The heart of the aircraft jet engine is considered by many to be the burner, for it is here that the heat is added producing high termal energy from which the engine is able to produce thrust.

The design of such an aircraft jet engine burner must take into account the following requirements:

(1) Low weight

(2) Compactness

(3) Low pressure loss

(4) Uniform temperature distribution at outlet

(5) A definite maximum temperature at outlet that is not to be exceeded

(6) Ability to withstand high temperatures structurally

(7) High combustion efficiency

(8) High rate of heat release

The first designs were arrived at by trial and error methods as only sketchy information was available. As burners were produced that could meet the above requirements, at least partially, certain concepts of design became accepted. How-

ever these concepts are continually being tested with varying configurations and still, to a great extent, with cut and try methods.

Requirements (4) and (5) are imposed by the material limitations of the turbine. These requirements, (4) and (5), are meet in the burner by dividing the airflow into roughly two parts, primary air and secondary air. Primary air, with the fuel, supports combustion and enters at the forward end of the burner. Secondary air enters the flame tube (inner liner of the burner), through various means, downstream of the primary air and serves to cool or quench the hot gases of combustion, thereby lowering the outlet temperature to the desired maximum or below. There is no sharp line of demarcation between primary and secondary air. This cooling by the secondary air should be done in such a manner that uniform temperature is obtained at burner outlet. The secondary air also aids in meeting requirement (6) by providing a cooling layer of air between flame tube and outer liner of the burner.

Ref. 1 defines combustion efficiency as the ratio of actual enthalpy increase of fuel plus working fluid to the ideal enthalpy increase if combustion were complete. Present day aircraft jet engine burners have high combustion efficiencies

and extremely high heat release rates over most of the operating range of the aircraft. Thus it might seem that there would be more productive fields of effort in which research and development could be channeled in man's attempts to improve the present day jet engine. However on a closer look at the complexities of the burner and its operation it becomes apparent that there is need for much improvement. For instance high combustion efficiency is limited to a restricted range of fuel-air ratios and as combustion efficiency drops, unstable burner operation and incomplete combustion results with the attendant loss in thrust and finally complete stoppage of the engine. Thus it becomes obvious that there is a great need for extending the range of burner operation with good combustion efficiency. The fact that jet engine burners have high combustion efficiencies over the operating range of the aircraft becomes merely a statement of the dependancy of the aircraft performance on combustion efficiency.

Poor combustion efficiency may be due to, according to Ref. 2:

(1) Excessive supply of primary air causing chilling of the combustion process, or to premature admission of the secondary air also causing chilling.

(2) Too long a flame path in relation to burner dimensions so that quenching of extreme portions of flame occurs, resulting in unburnt fuel.

From the above it can be seen that the secondary air of the burner becomes very important and the manner in which it is introduced into the flame tube has a marked effect upon combustion efficiency. Thus the distribution and mixing rate of the secondary air with the hot gases of combustion assumes a critical place in the overall picture of the aircraft jet engine.

It was the purpose of this investigation to survey the temperature of the secondary air mixing zone and with the results so obtained to attempt to provide an insight into the mixing rates and pattern of mixing within the burner. To carry out this purpose a typical "can" type burner that has been used successfully in an aircraft turbo-jet engine was selected. This burner was part of the J33-A-17 turbo-jet engine.

## TEST EQUIPMENT

A schematic drawing of the test equipment is presented in Fig. 1. Fig. 2 shows the control panel from which the test equipment in the test cell was operated. Engine instruments and controls were located at the control panel.

A six cylinder Lycoming engine, Model 9-435-T rated at 182 hp. at 2800 RPM was directly coupled to a centrifugal compressor with a 7.48 : 1 gear ratio. This compressor was removed from an Allison V-1710 Aircraft Engine. The installation is pictured in Fig. 3.

The air to the compressor entered an eight in. duct, in the test cell, in which there was placed a 5.6 in. square edged orifice with radius taps. Pressure lines from the radius taps were lead to the control panel and there connected to a water filled manometer so that differential pressure, $\Delta p_w$, across the orifice could be read directly at this location.

Compressed air from the compressor then entered a large duct, as shown in Fig. 3, and was lead to the J33-A-17 turbo jet engine burner, a "can" type, where it was mixed with fuel and the resulting mixture burned. The hot gases and excess air were then blown through an exhaust system to the out-

side atmosphere.

The fuel used in the burner was diesel oil and was lead from a tank outside the test cell to a fuel rotameter that indicated fuel flow in pounds per hour. From the rotameter the fuel went to a fuel pump with a by pass arrangement to allow control over the fuel flow rate. The pump sent the fuel directly to the spray type fuel nozzle in the burner.

Ignition was accomplished by means of a spark plug first igniting a stream of acetylene and then, after starting the fuel pump, the burning acetylene ignited the fuel. The acetylene was supplied from a standard tank, lead through a relay control for positive operation, and then to the sleeve of the spark plug and out into the burner.

A sketch of the J33-A-17 Turbo Jet Engine burner is shown in Fig. 4 giving the dimensions, size and location of the secondary air passages, and position of fuel nozzle and spark plug. The flame tube has seven rows of holes of which three of the rows are shown in Fig. 4. The rows are equally spaced around the tube. There are also seven rows of air slits of which three rows are shown in Fig. 4. Fig. 5 is a picture of the flame tube removed from the outer shell. There are two large holes of 1.2 in. diameter of which one is

shown in Fig. 4. These are for starting purposes when installed in the complete engine and were blocked off for this test to prevent the entry of secondary air by this means.

To carry out the purpose of this investigation four stations were first selected along the burner as shown in Fig. 4. Then, to permit the temperature probing of the secondary air mixing zone, 11/32 in. holes were drilled around the periphery of the outer liner, one hole in line with each of the secondary air holes in the flame tube at the stations selected. Metal plates, 3 3/8 by 1 3/8 in., and 1/4 in. thick were cut from 8 in. pipe to give them some curvature. 11/32 in. holes were then drilled in the metal plates to correspond to the holes previously cut in the outer liner. The holes in the plates were then tapped and the plates riveted in place to the outer liner. One eighth pipe plugs were then screwed in the holes so prepared so as to seal them when not in use. In this manner access for the thermocouples was provided to the flame tube at the four stations and at all seven secondary air holes at each station, except at station 1 and 4, where previous work on the burner prevented the cutting of a hole on the outer liner in line with the seventh secondary air hole of the flame tube.

3/16 in. holes were then drilled through seven of the one eighth pipe plugs. These pipe plugs were then used when temperature measurements were to be made at a station, the thermocouple being inserted in the 3/16 in. holes and on into the flame tube. Small set screws were provided on the sides of the pipe plugs to hold the thermocouples in place.

The thermocouples were of the iron-constatan type. They were lead from the burner to a junction box within the test cell and then to a selector switch on the control panel. The selector switch was connected to a Brown Temperature Recorder of the potentiometer type which read in degrees Fahrenheit from 0 to 1600. Ceramic insulators covering six inches of thermocouple wiring were placed around each thermocouple next to the bead.

Total pressure, $p_o$, and static pressure, p, were measured at a station 12 in. ahead of the burner. Pressure lines were lead from a total head tube and a static orifice to two mercury filled manometers at the control panel. A thermocouple was also inserted in the stream at this point and connected to the thermocouple control switch at the control panel.

A thermocouple was also provided at the entrance to the inlet air duct to the compressor and connected to the control switch.

## TEST PROCEDURE

It was first decided to measure the temperature at each station and each secondary air hole from the center of the flame tube out in steps of 1/2 in. Then, for the purpose of identification, each row was assigned a letter. Thus each secondary air hole could be designated by a combination of station number and letter indicating the row. For example 1A designated the secondary air hole in the A row at the first station. Each position of the bead of the thermocouple, as it moved in 1/2 in. increments from the center, was also assigned a number to follow the row designation. The center was indicated by 0, the position 1/2 in. away from the center by 1 and so on. Thus 3C4 indicated a position two inches from the center of the flame tube at station 3 and row C.

To obtain the temperature readings the thermocouples were placed in position at station 4 and three in. from the center, that is, at 4A6, 4B6, etc., one thermocouple at each secondary air hole at that station. The engine was then started and warmed up and the fuel to the burner ignited. The engine RPM was set to obtain the desired air flow through the burner and the burner fuel pressure regulated to give desired

## TEST PROCEDURE

It was first decided to measure the temperature at each station and each secondary air hole from the center of the flame tube out to a depth of 1/2 in. Thus, for the purpose of identification, each row was assigned a letter; thus each secondary air hole could be designated by a combination of [illegible] number and letter indicating the row. For example 1A designates the secondary air hole in the A row at the first station. Each position of the head of the thermocouple, as it moved in 1/8 in. increments from the center, was also assigned a number to follow the row designation. The center was designated by 0, the position 1/8 in. away from the center by 1 and so on. Thus 2A4 indicates a position 1/2 inch from the center of the flame tube at station 2 and row A.

To obtain the temperature readings the thermocouples were placed in position at station 2 and three in. from the center, that is, at [illegible], etc., one thermocouple at each secondary air hole at that station. The engine was then started and warmed up and the fuel to the burner [illegible]. The engine [illegible] was set to obtain the desired air flow through the burner and the burner fuel pressure regulated to give desired

[illegible]

fuel flow. The temperatures were then read and recorded by two men at the control panel who were also maintaining desired air and fuel flow. Two men in the test cell then repositioned the thermocouples by hand to positions 4A5, 4B5, 4C5, etc., and again the temperatures were read and recorded. The thermocouples were positioned by means of wooden guides previously marked to indicate correct distances, from the top of the pipe plugs to the end of the ceramic insulators, corresponding to the desired position of the thermocouple bead within the flame tube. This was repeated until all of the station 4 readings had been obtained. The engine was then stopped and the thermocouples shifted to station 3 where the procedure was repeated. In this manner the temperatures were measured at all four stations. Two such runs were made, Run 1 at a fuel-air ratio of .012 and Run 2 at a fuel-air ratio of .009.

Fig. 6 shows the thermocouples positioned at 2A4, 2B4, 2C4, etc. as described above.

## TEST RESULTS AND DISCUSSION

The temperatures obtained in the survey, and the test cell operating conditions, are presented in Tables I and II for Runs 1 and 2 respectively. The test cell conditions simulated the following J33-A-17 turbo jet engine operating conditions:

Run 1

| | |
|---|---|
| Fuel-air ratio | .012 |
| Altitude | 3900 feet |
| Engine speed | 5400 RPM |
| Air flow | 8000 lb/hr |

Run 2

| | |
|---|---|
| Fuel-air ratio | .009 |
| Altitude | 4000 feet |
| Engine speed | 5350 RPM |
| Air flow | 7950 lb/hr |

Perhaps what is more important is that the test cell conditions also approximate the critical engine condition of blowout at high altitude. Thus if the engine were operating at, say 30,000 feet and 12,000 actual RPM the same conditions that existed in the test cell would be approached by the engine.

According to Ref. 9, at an altitude of 30,000 feet and 12,000 actual RPM a fuel-air ratio of .021 would be necessary. As can be seen above, the actual fuel-air ratios employed in the tests were much less. It is thought that lean fuel-air ratios, as used in the test, are a primary cause of blowout. Thus one can say that burner conditions were such that blowout might have been approached. However, no such conditions were noticed. That is stable operations were perceived throughout and the results gave no indications of an impending blowout.

The results in Tables I and II are shown plotted in Figs. 7 through 16. In Figs. 7 through 10 and 12 through 15 the burner is drawn full scale and in the position with respect to the vertical that it occupied during the tests. The outer liner is represented by the full circle and the flame tube by the dashed circle showing location of the secondary air holes.

From a study of the temperature patterns, Figs. 7 through 10 and 12 through 15, obtained at the various stations, as located in Fig. 4, it becomes apparent that the hot core of the combustion gases travels down the burner very near to the center. At each succeeding station the hot gases of the center are cooled as the secondary air takes effect, thus producing a sort of truncated cone effect. The higher temperatures

[illegible]

[illegible]

[illegible]

found near the center in Run 1, with a fuel-air ratio of .012, over those of Run 2, with a fuel-air ratio of .009, for corresponding stations, indicates the effect of increasing fuel-air ratio.

High temperature gradients are encountered, in both Runs, at station 1, Figs. 7 and 12. As the gases proceed downstream the contour lines become spaced farther apart and also become less uniform thus indicating that the secondary air mixing is causing the temperature differences within the flame tube to be reduced. The nonuniformity of the contour lines indicates the turbulance of the process. There appears to be, however, a certain pattern even with respect to the turbulance as indicated by the contour lines, as the same general indications were obtained in both runs. The patterns, although becoming less circular and roughly more elliptical in shape, show a uniformity with respect to temperature decrease that indicates stable operation and fairly good mixing. By the time station 4 has been reached the temperatures within the immediate area of the center have become equalized to a certain extent and a steadily increasing temperature gradient to the center, so noticeable at the other stations, has begun to be broken up. The appearance of comparatively high temperature peaks at

places other than the center gives evidence of this.

To show in a different manner the effect of mixing and mixing rates, the temperature profiles at the various stations have been drawn as shown in Figs. 11 and 16 for Runs 1 and 2 respectively. The temperatures for these figures were arrived at by dividing the burner, as shown in the temperature pattern figures, into two parts by drawing a horizontal line through the center. At each radius from the center the top three readings were averaged for the top point and the bottom four points averaged for the bottom point. These profiles show that as the secondary air mixes the peak of the curves are reduced and at the same time the curves themselves are flattened out. That is the slopes at about 0.5 in. to 2.0 in. radius more nearly approach the vertical. This is desireable as a uniform temperature, i.e., a vertical profile, is the ideal with perhaps the variation of a low temperature existing at the turbine blade root. Of course this condition should not be attained at the expense of too low a temperature. Notice that the slope of the profiles of Figs. 11 and 16 between a radius of two and three in. are practically constant from station 2 on to 4. The same phenomenon may be observed in Figs. 7 through 10 and 12 through 15. This seems to indicate that the secondary air does not cool the temperature of

places other than the center gives evidence of this.

To show in a different manner the effect of mixing and mixing rates, the temperature profiles at the various stations have been drawn as shown in Figs. 11 and 12 for runs 1 and 2 respectively. The temperatures for these figures were obtained by [illegible] the readings, as shown in the temperature pattern figures, into two parts by drawing a horizontal line through the center. At each station then the [illegible] three readings were averaged for the top point and the center four points averaged for the bottom point. These profiles show that as the secondary air mixes the peak of the curves are reduced and at the same time the curves themselves are flattened out. That is the slopes at which [illegible] more nearly approach the vertical. This is desirable as a uniform temperature, i.e., a vertical profile, is the ideal with perhaps the variation of a few degrees [illegible] at the turbine-blade roots. Of course this condition should not be attained at the expense of too low a temperature. Notice that the slope of the profiles of Figs. 11 and 12 becomes a [illegible] from station 2 on to 4. The [illegible] may be observed [illegible] Figs. [illegible] through [illegible]. This seems to indicate that the secondary air [illegible] the temperature [illegible]

the mixture within the burner, around the outer radii of the flame tube beyond a certain point. As more secondary air enters it apparently penetrates farther and farther into the flame tube therefore having a much greater effect upon the hotter gases. In other words, as the amount of secondary air into the flame tube increases the gases seem to be cooled, in concentric layers, to certain temperatures and then remain fairly constant. This is good from a structural standpoint as low temperatures are maintained at the outer boundaries. However with regard to the requirement that uniform temperatures exist across the outlet it is not so good as it is apparent that low temperatures will prevail around the edges with high temperatures generally in the center. Thus, in this burner, some additional arrangement must be provided to give a closer approach to uniform distribution at the outlet. From Fig. 4 it can be seen that the burner converges for twelve in. aft of station 4 and whether this results in better temperature outlet conditions or not is not known but would be a subject for additional investigation.

One solution for obtaining uniform temperature distribution at the outlet in this type of burner would be to introduce, by some means, a portion of the secondary air into the flame tube at the center of the flame tube and downstream of

the mixture within the burner, probably the outer shell of the flame tube beyond a certain point. As more secondary air enters it apparently penetrates farther and farther into the flame tube [illegible], a much greater effect upon the hotter gases. In other words, as the amount of secondary air into the flame tube increases the gases seem to be cooled, in [illegible] [illegible], to certain temperatures and then remain fairly constant. This is good from a structural standpoint as the temperatures are maintained at the lower magnitudes. However with regard to the requirement that uniform temperatures exist across the outlet it is not so good as it is observed that the temperatures will [illegible] toward the edges with the temperatures [illegible] in the center. Thus, in this burner, some additional arrangement must be provided to give a closer approach to uniform distribution at the outlet. From Fig. [illegible] it can be seen that the [illegible] [illegible] and the [illegible] [illegible] of station 4 are [illegible] this [illegible] to [illegible] the [illegible] outlet conditions so [illegible] [illegible] [illegible] would be a subject for additional investigation.

[illegible] the solution for obtaining uniform temperature distribution at the outlet in this type of burner would be to introduce, by some means, a portion of the secondary air into the flame tube at the center of the flame tube and downstream of

the combustion process. This would mean that struts or piping would have to be placed within the flame tube which would result in a higher pressure loss through the burner. Whether the temperature achieved would warrent the increased pressure loss is unknown and would be another subject for investigation. The placing of baffles within the flame tube in such a manner that the low temperature mixture near the outer radii is mixed with the high temperature mixture in the center region might also provide better temperature distribution at the outlet.

# CONCLUSIONS

From the temperatures obtained from within the J33-A-17 Turbo Jet Engine can type burner during operation, at fuel-air ratios of .009 and .012, the following conclusions can be drawn:

(1) The hot core of the combustion gases travels approximately down the center of the flame tube.

(2) Increasing the fuel-air ratio seems to increase, in the secondary air mixing zone, only the temperatures near the center of the flame tube. That is, enough secondary air is being admitted to the flame tube to cool the hot gases to practically constant temperatures near the outer boundaries of the flame tube.

(3) The secondary air between the flame tube and outer liner remains at a comparatively constant temperature.

(4) The temperatures on both sides of the flame tube are low enough so that the structural tempera-

ture limit is not exceeded.

(5) This type of burner and secondary air arrangement gives stable operation at the engine operating conditions (even, it is believed, approaching blowout) under which the test was conducted and produces a fairly uniform mixing of air and combustion gases.

(6) The mixing of secondary air and gases is such that uniform temperature distribution is being approached when the secondary air has ceased to be admitted. However, the low temperatures near the outer radii are being maintained and it is the high temperatures near the center that are being reduced. Thus a temperature gradient still remains at this point.

(7) To produce a uniform temperature distribution at the point where secondary air ceases to be admitted, or slightly downstream, some additional arrangement would be necessary to raise the outer temperatures.

# TABLE 1

Observed Data and Test Cell Operating Conditions, Run 1.

| Station 1 Position | Station 1 °F | Station 2 Position | Station 2 °F | Station 3 Position | Station 3 °F | Station 4 Position | Station 4 °F |
|---|---|---|---|---|---|---|---|
| 1A6 | 190 | 2A6 | 180 | 3A6 | 170 | 4A6 | 180 |
| 1B6 | 190 | 2B6 | 180 | 3B6 | 170 | 4B6 | 180 |
| 1C6 | 185 | 2C6 | 180 | 3C6 | 170 | 4C6 | 180 |
| 1D6 | 195 | 2D6 | 170 | 3D6 | 175 | 4D6 | 180 |
| 1E6 | 195 | 2E6 | 160 | 3E6 | 190 | 4E6 | 180 |
| 1F6 | 170 | 2F6 | 190 | 3F6 | 175 | 4F6 | 180 |
| | | 2G6 | 195 | 3G6 | 180 | | |
| 1A5 | 275 | 2A5 | 420 | 3A5 | 240 | 4A5 | 270 |
| 1B5 | 300 | 2B5 | 250 | 3B5 | 590 | 4B5 | 370 |
| 1C5 | 280 | 2C5 | 440 | 3C5 | 430 | 4C5 | 390 |
| 1D5 | 550 | 2D5 | 490 | 3D5 | 450 | 4D5 | 410 |
| 1E5 | 350 | 2E5 | 260 | 3E5 | 250 | 4E5 | 250 |
| 1F5 | 830 | 2F5 | 520 | 3F5 | 580 | 4F5 | 370 |
| | | 2G5 | 210 | 3G5 | 250 | | |
| 1A4 | 900 | 2A4 | 450 | 3A4 | 410 | 4A4 | 490 |
| 1B4 | 1000 | 2B4 | 390 | 3B4 | 560 | 4B4 | 600 |
| 1C4 | 1150 | 2C4 | 990 | 3C4 | 800 | 4C4 | 1130 |
| 1D4 | 1580 | 2D4 | 530 | 3D4 | 760 | 4D4 | 610 |
| 1E4 | 1540 | 2E4 | 400 | 3E4 | 930 | 4E4 | 530 |
| 1F4 | 1080 | 2F4 | 530 | 3F4 | 920 | 4F4 | 690 |
| | | 2G4 | 370 | 3G4 | 430 | | |
| 1A3 | 1580 | 2A3 | 890 | 3A3 | 770 | 4A3 | 710 |
| 1B3 | 1580 | 2B3 | 1580 | 3B3 | 710 | 4B3 | 770 |
| 1C3 | 1580 | 2C3 | 1290 | 3C3 | 1250 | 4C3 | 1310 |
| 1D3 | 1580 | 2D3 | 1380 | 3D3 | 1240 | 4D3 | 940 |
| 1E3 | 1580 | 2E3 | 1580 | 3E3 | 1010 | 4E3 | 830 |
| 1F3 | 1580 | 2F3 | 1030 | 3F3 | 1140 | 4F3 | 1120 |
| | | 2G3 | 900 | 3G3 | 840 | | |
| 1A2 | | 2A2 | 1580 | 3A2 | 920 | 4A2 | 940 |
| 1B2 | | 2B2 | 1580 | 3B2 | 1560 | 4B2 | 1090 |
| 1C2 | | 2C2 | 1580 | 3C2 | 1300 | 4C2 | 1240 |
| 1D2 | | 2D2 | 1580 | 3D2 | 1550 | 4D2 | 1500 |
| 1E2 | | 2E2 | 1580 | 3E2 | 1580 | 4E2 | 1580 |
| 1F2 | | 2F2 | 1580 | 3F2 | 1560 | 4F2 | 1240 |
| | | 2G2 | 1580 | 3G2 | 1400 | | |
| 1A1 | | 2A1 | | 3A1 | 1580 | 4A1 | 1400 |
| 1B1 | | 2B1 | | 3B1 | 1580 | 4B1 | 1450 |
| 1C1 | | 2C1 | | 3C1 | 1580 | 4C1 | 1400 |
| 1D1 | | 2D1 | | 3D1 | 1580 | 4D1 | 1580 |
| 1E1 | | 2E1 | | 3E1 | 1580 | 4E1 | 1580 |
| 1F1 | | 2F1 | | 3F1 | 1580 | 4F1 | 1540 |
| | | 2G1 | | 3G1 | 1580 | | |
| 1A0 | | 2A0 | | 3A0 | | 4A0 | 1580 |
| 1B0 | | 2B0 | | 3B0 | | 4B0 | 1580 |
| 1C0 | | 2C0 | | 3C0 | | 4C0 | 1580 |
| 1D0 | | 2D0 | | 3D0 | | 4D0 | 1580 |
| 1E0 | | 2E0 | | 3E0 | | 4E0 | 1580 |
| 1F0 | | 2F0 | | 3F0 | | 4F0 | 1580 |
| | | 2G0 | | 3G0 | | | |

| Engine Speed. | Dissercation orifice pressure, $\Delta P_w$ | Fuel Pressure. | Fuel Flow, $w_f$ | Burner Inlet Static Press. $P$ | Burner Inlet Total Press. $P_o$ | Burner Inlet Temp. $T_i$ | Compressor Intake Temp. $T_o$ | Barometer $P_a$ | Ambient Temp. $T_a$ |
|---|---|---|---|---|---|---|---|---|---|
| RPM | In. $H_2O$ | lb/in² gage | lb/hr | In. Hg. | In. Hg. | °F | °F | In. Hg. | °F |
| 2420 | 14.8 | 85 | 97 | 37.8 | 38.29 | 170 | 95 | 29.29 | 85.0 |

# TABLE II

Observed Data and Test Cell Operating Conditions, Run 2.

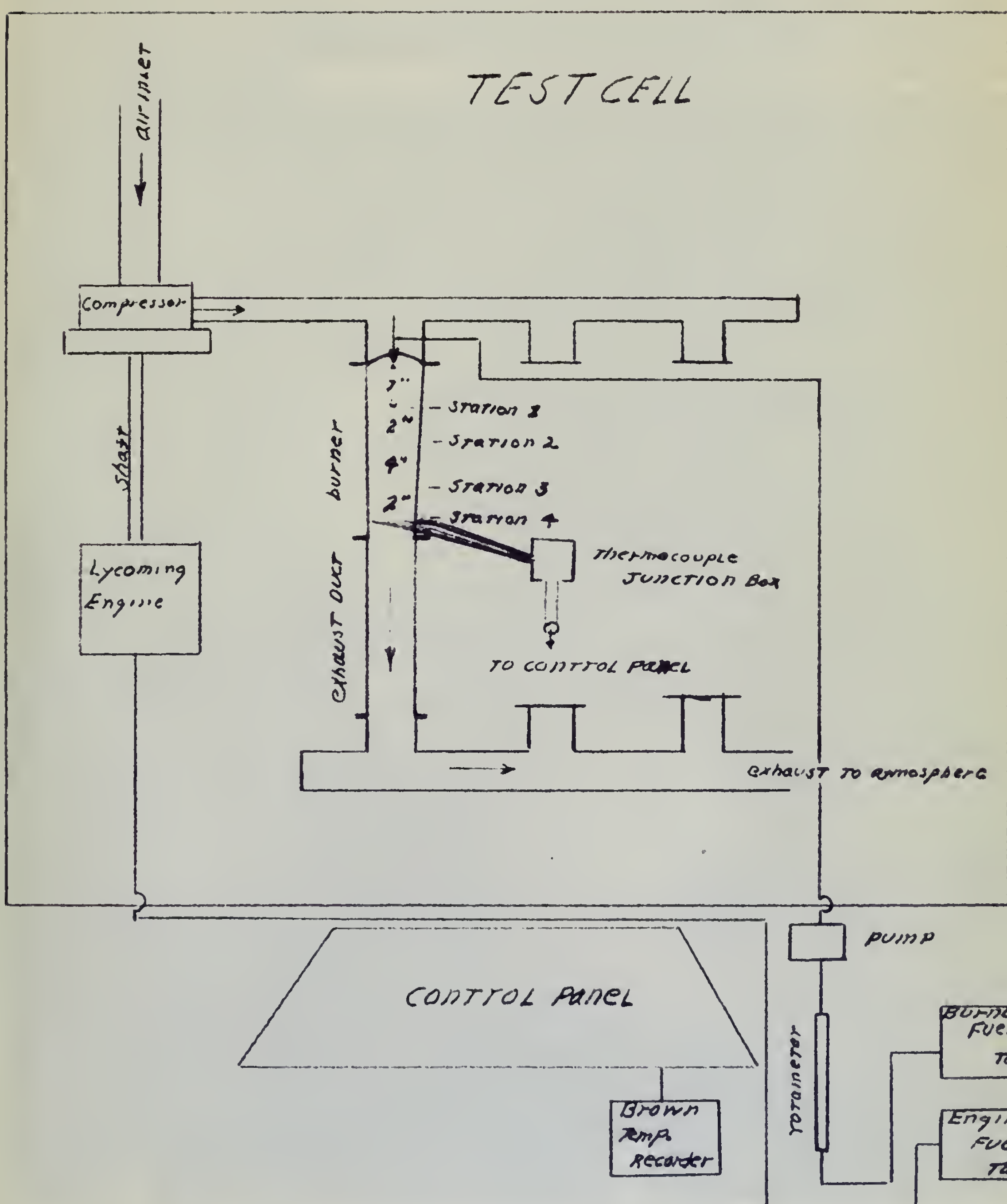
| Station 1 | | Station 2 | | Station 3 | | Station 4 | |
|---|---|---|---|---|---|---|---|
| Position | °F | Position | °F | Position | °F | Position | °F |
| 1A6 | 185 | 2A6 | 190 | 3A6 | 190 | 4A6 | 195 |
| 1B6 | 185 | 2B6 | 190 | 3B6 | 190 | 4B6 | 195 |
| 1C6 | 185 | 2C6 | 190 | 3C6 | 195 | 4C6 | 195 |
| 1D6 | 190 | 2D6 | 195 | 3D6 | 195 | 4D6 | 190 |
| 1E6 | 185 | 2E6 | 195 | 3E6 | 195 | 4E6 | 195 |
| 1F6 | 190 | 2F6 | 195 | 3F6 | 195 | 4F6 | 190 |
| | | 2G6 | 195 | 3G6 | 195 | | |
| 1A5 | 300 | 2A5 | 345 | 3A5 | 195 | 4A5 | 285 |
| 1B5 | 240 | 2B5 | 285 | 3B5 | 240 | 4B5 | 285 |
| 1C5 | 300 | 2C5 | 970 | 3C5 | 510 | 4C5 | 560 |
| 1D5 | 480 | 2D5 | 340 | 3D5 | 475 | 4D5 | 440 |
| 1E5 | 290 | 2E5 | 270 | 3E5 | 250 | 4E5 | 240 |
| 1F5 | 630 | 2F5 | 400 | 3F5 | 545 | 4F5 | 500 |
| | | 2G5 | 290 | 3G5 | 315 | | |
| 1A4 | 870 | 2A4 | 420 | 3A4 | 300 | 4A4 | 485 |
| 1B4 | 770 | 2B4 | 360 | 3B4 | 440 | 4B4 | 460 |
| 1C4 | 1000 | 2C4 | 730 | 3C4 | 1100 | 4C4 | 1090 |
| 1D4 | 1360 | 2D4 | 590 | 3D4 | 900 | 4D4 | 600 |
| 1E4 | 960 | 2E4 | 400 | 3E4 | 370 | 4E4 | 405 |
| 1F4 | 1210 | 2F4 | 460 | 3F4 | 765 | 4F4 | 1040 |
| | | 2G4 | 610 | 3G4 | 730 | | |
| 1A3 | 1580 | 2A3 | 630 | 3A3 | 740 | 4A3 | 610 |
| 1B3 | 1560 | 2B3 | 660 | 3B3 | 600 | 4B3 | 660 |
| 1C3 | 1570 | 2C3 | 1050 | 3C3 | 1120 | 4C3 | 1075 |
| 1D3 | 1580 | 2D3 | 1400 | 3D3 | 910 | 4D3 | 810 |
| 1E3 | 1580 | 2E3 | 1385 | 3E3 | 570 | 4E3 | 690 |
| 1F3 | 1560 | 2F3 | 1410 | 3F3 | 910 | 4F3 | 1005 |
| | | 2G3 | 1580 | 3G3 | 1050 | | |
| 1A2 | | 2A2 | 1580 | 3A2 | 800 | 4A2 | 835 |
| 1B2 | | 2B2 | 1580 | 3B2 | 870 | 4B2 | 810 |
| 1C2 | | 2C2 | 1580 | 3C2 | 1150 | 4C2 | 1040 |
| 1D2 | | 2D2 | 1580 | 3D2 | 1240 | 4D2 | 1150 |
| 1E2 | | 2E2 | 1580 | 3E2 | 1480 | 4E2 | 1230 |
| 1F2 | | 2F2 | 1580 | 3F2 | 1370 | 4F2 | 1200 |
| | | 2G2 | 1580 | 3G2 | 1580 | | |
| 1A1 | | 2A1 | | 3A1 | 1140 | 4A1 | 1065 |
| 1B1 | | 2B1 | | 3B1 | 1210 | 4B1 | 1030 |
| 1C1 | | 2C1 | | 3C1 | 1320 | 4C1 | 1180 |
| 1D1 | | 2D1 | | 3D1 | 1580 | 4D1 | 1380 |
| 1E1 | | 2E1 | | 3E1 | 1580 | 4E1 | 1480 |
| 1F1 | | 2F1 | | 3F1 | 1580 | 4F1 | 1420 |
| | | 2G1 | | 3G1 | 1580 | 4G1 | |
| 1A0 | | 2A0 | | 3A0 | 1490 | 4A0 | 1380 |
| 1B0 | | 2B0 | | 3B0 | 1490 | 4B0 | 1380 |
| 1C0 | | 2C0 | | 3C0 | 1410 | 4C0 | 1380 |
| 1D0 | | 2D0 | | 3D0 | | 4D0 | 1380 |
| 1E0 | | 2E0 | | 3E0 | | 4E0 | 1380 |
| 1F0 | | 2F0 | | 3F0 | | 4F0 | 1380 |
| | | 2G0 | | 3G0 | | | |

| Engine Speed | Differential Orifice Pressure $\Delta P_H$ | Fuel Pressure | Fuel Flow $W_f$ | Burner Inlet Static Press $p$ | Burner Inlet Total Press $P_2$ | Burner Inlet Temp. $T_2$ | Compressor Intake Temp. $T_0$ | Barometer $P_b$ | Ambient Temp. $T_a$ |
|---|---|---|---|---|---|---|---|---|---|
| RPM | in. $H_2O$ | lb/in.² gage | lb/hr. | in. Hg | in. Hg | °F | °F | in. Hg | °F |
| 2420 | 14.8 | 74 | 74 | 37.2 | 37.57 | 185 | 105 | 29.27 | 88 |

-22-

FIG. 1

Schematic of Test Equipment



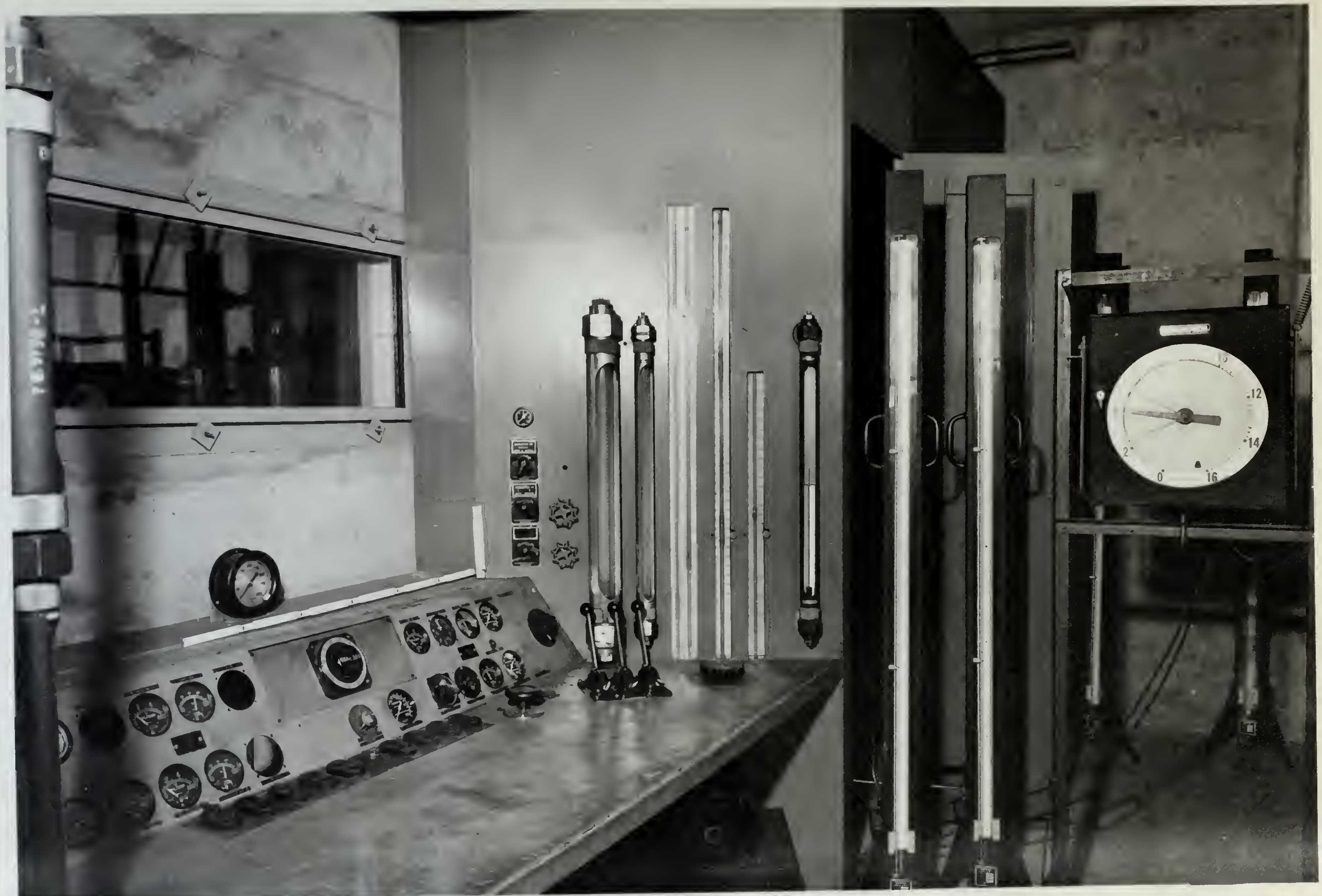


Figure 2. Control Panel

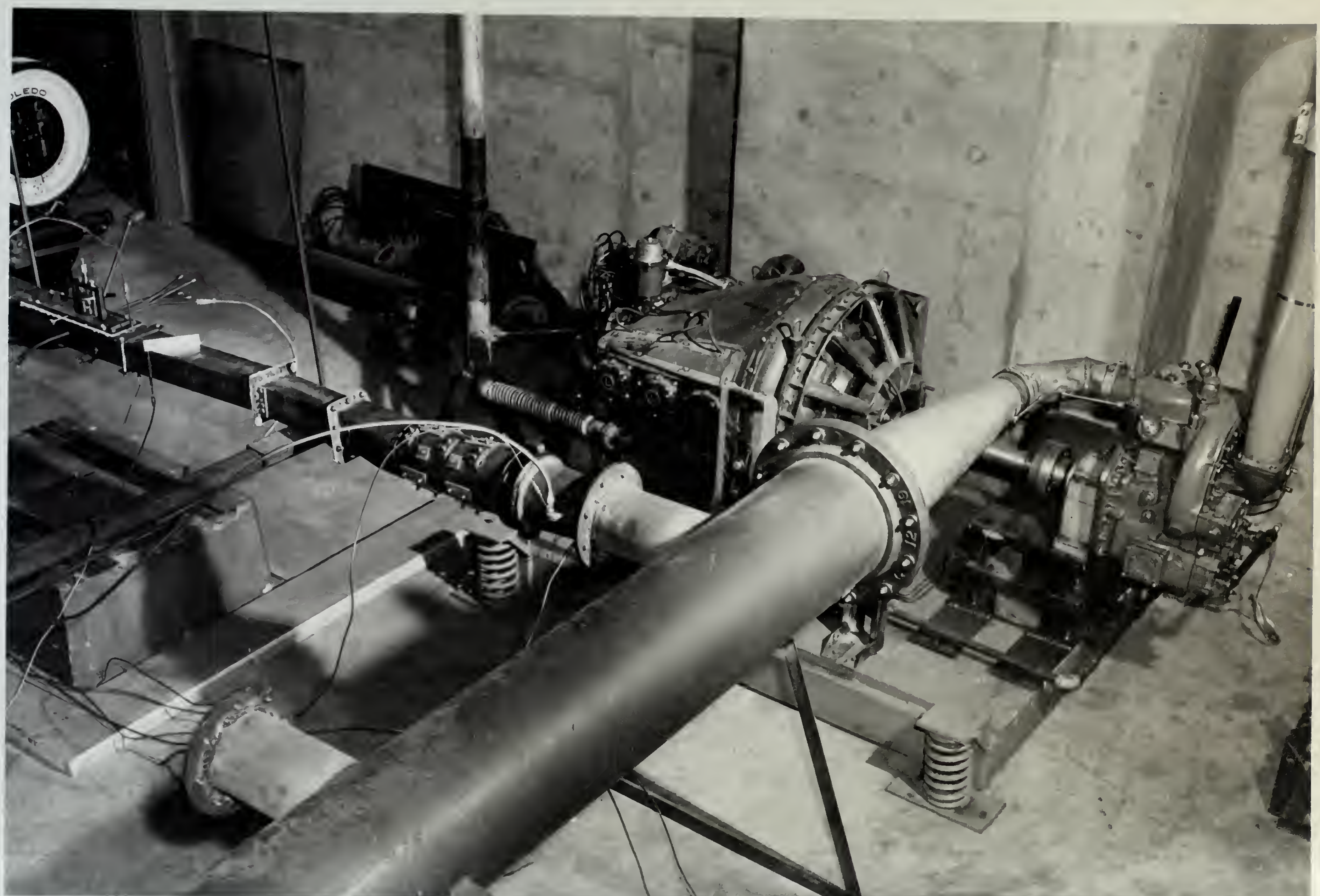
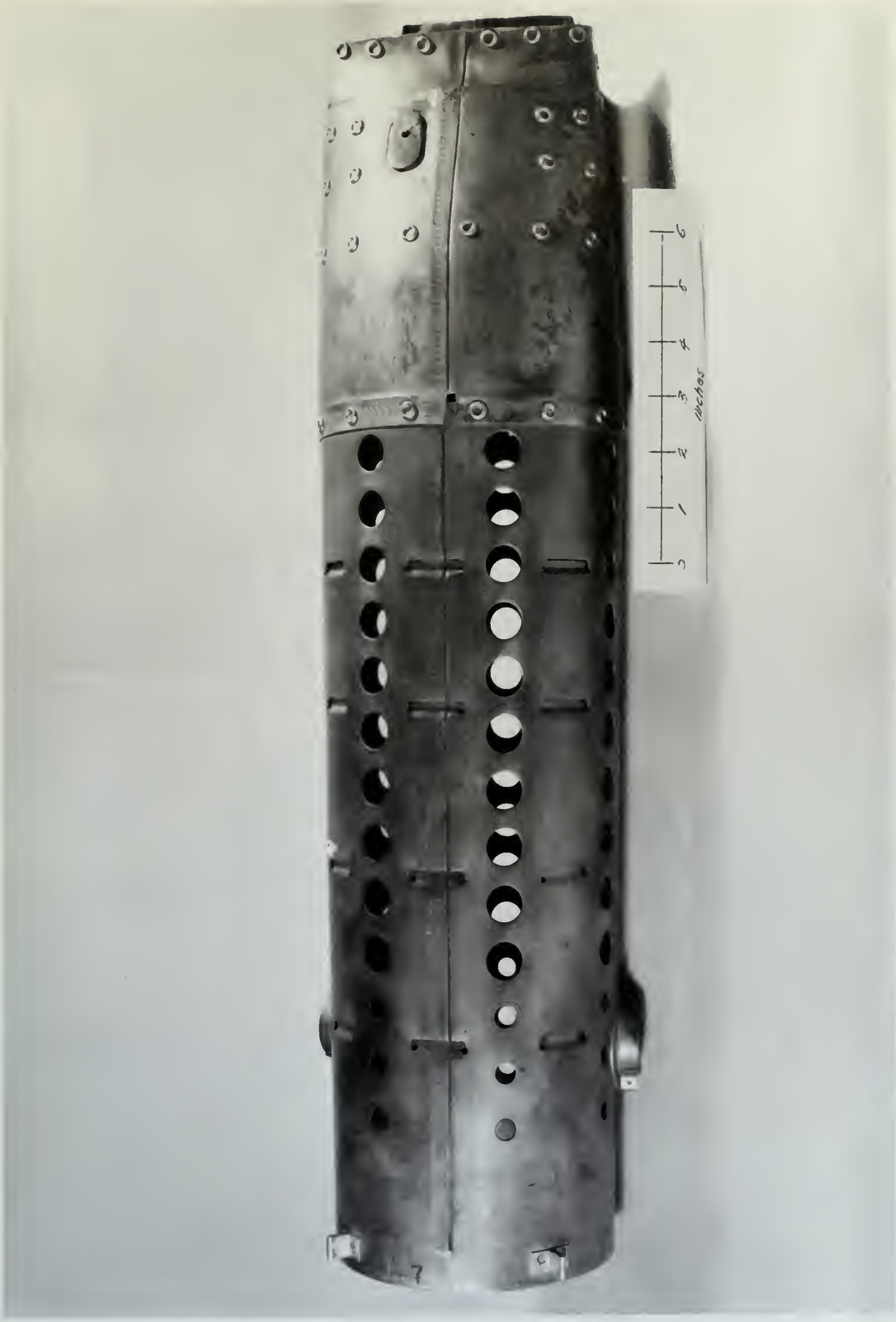


Figure 7. [illegible] Compressor and Burner

FIG. 4

Sketch of a J33-A-17 turbo jet engine burner


inches

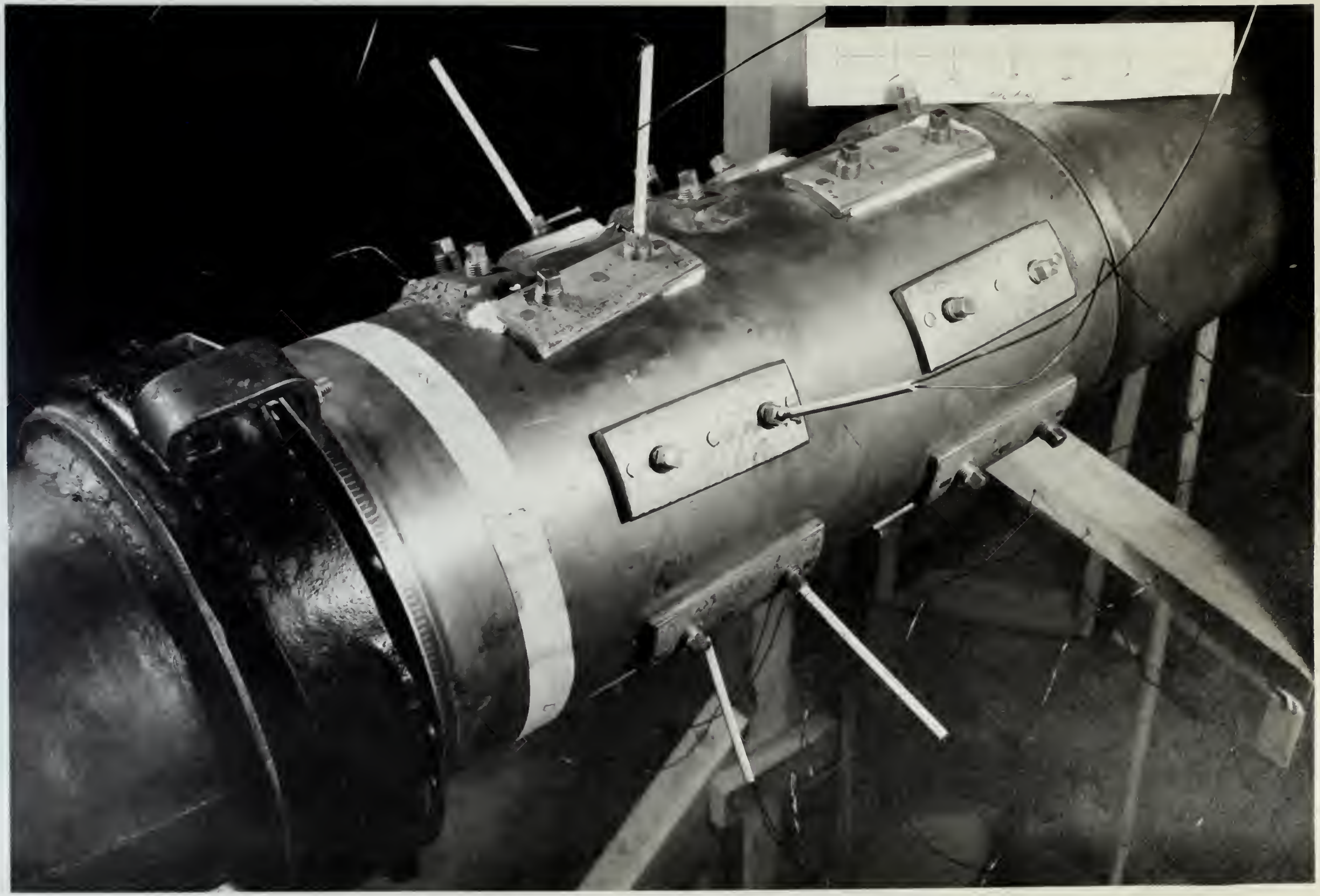
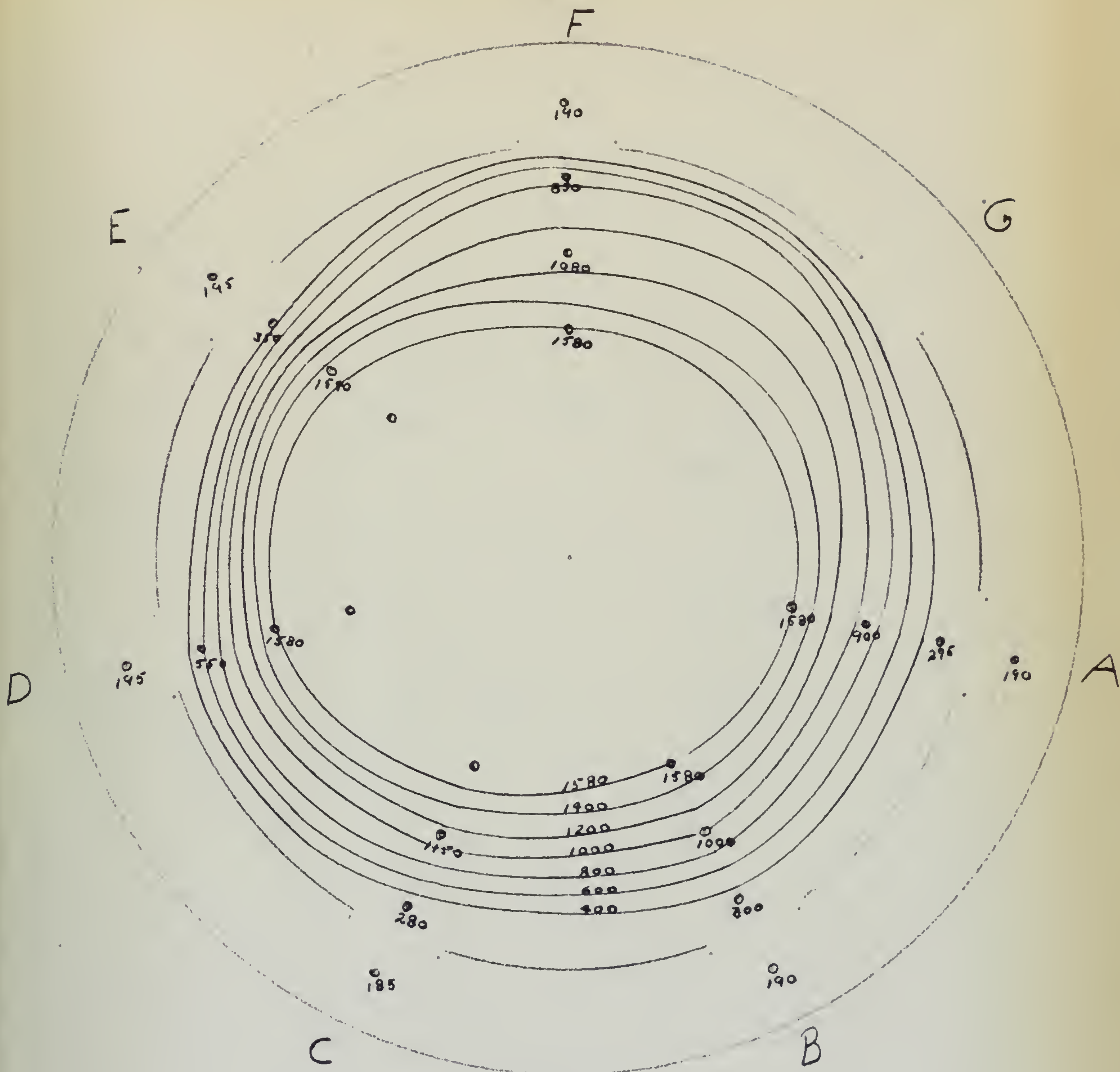


Figure 8. Thermocouples Installed in Burner

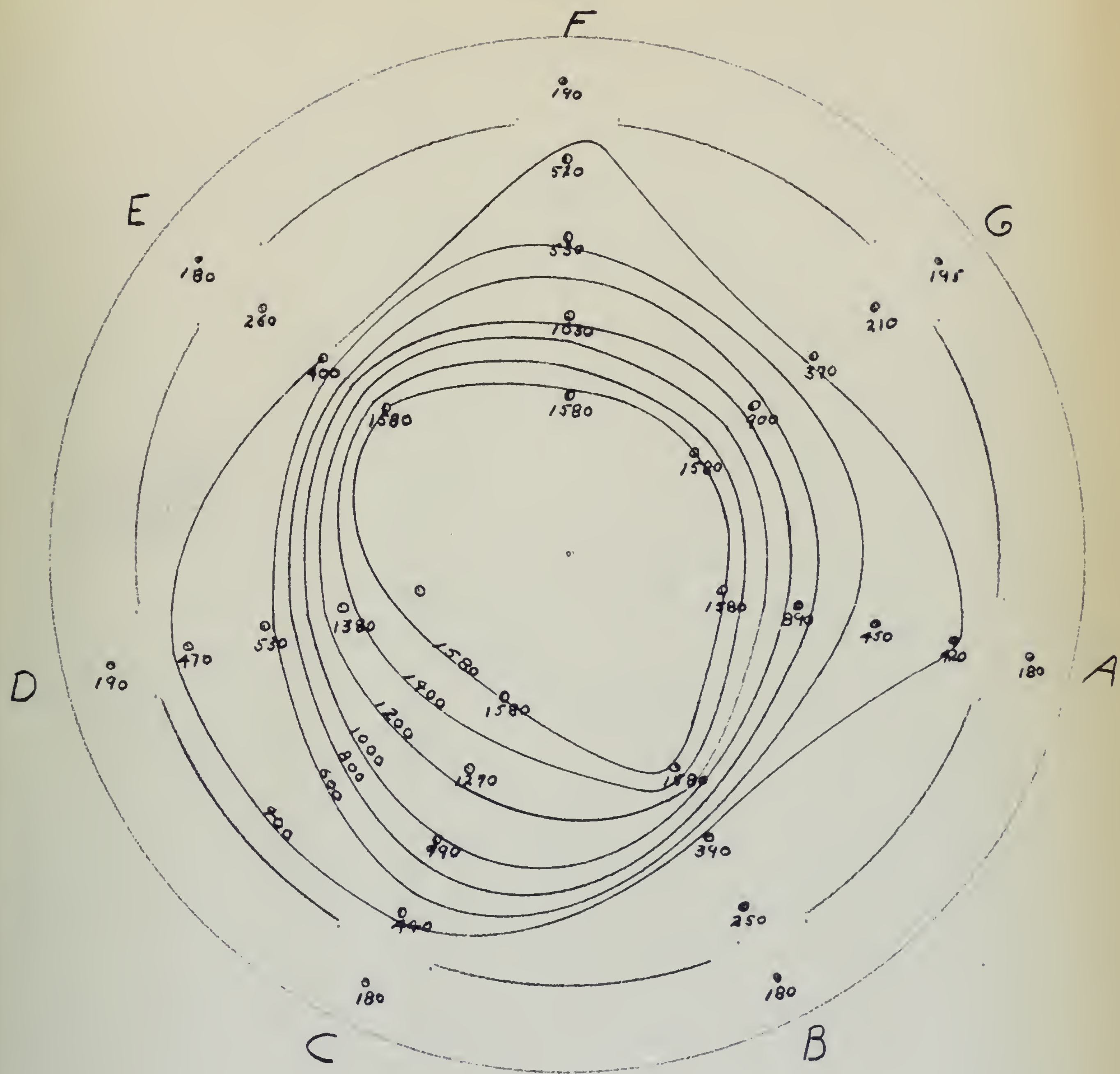
Figure 7




Temperature pattern at station 1. Operating conditions: Fuel-air ratio, .012; altitude, 3900 feet; engine speed, 5400 RPM. All temperatures in $^{o}$F.

(High altitude blowout condition being approached)

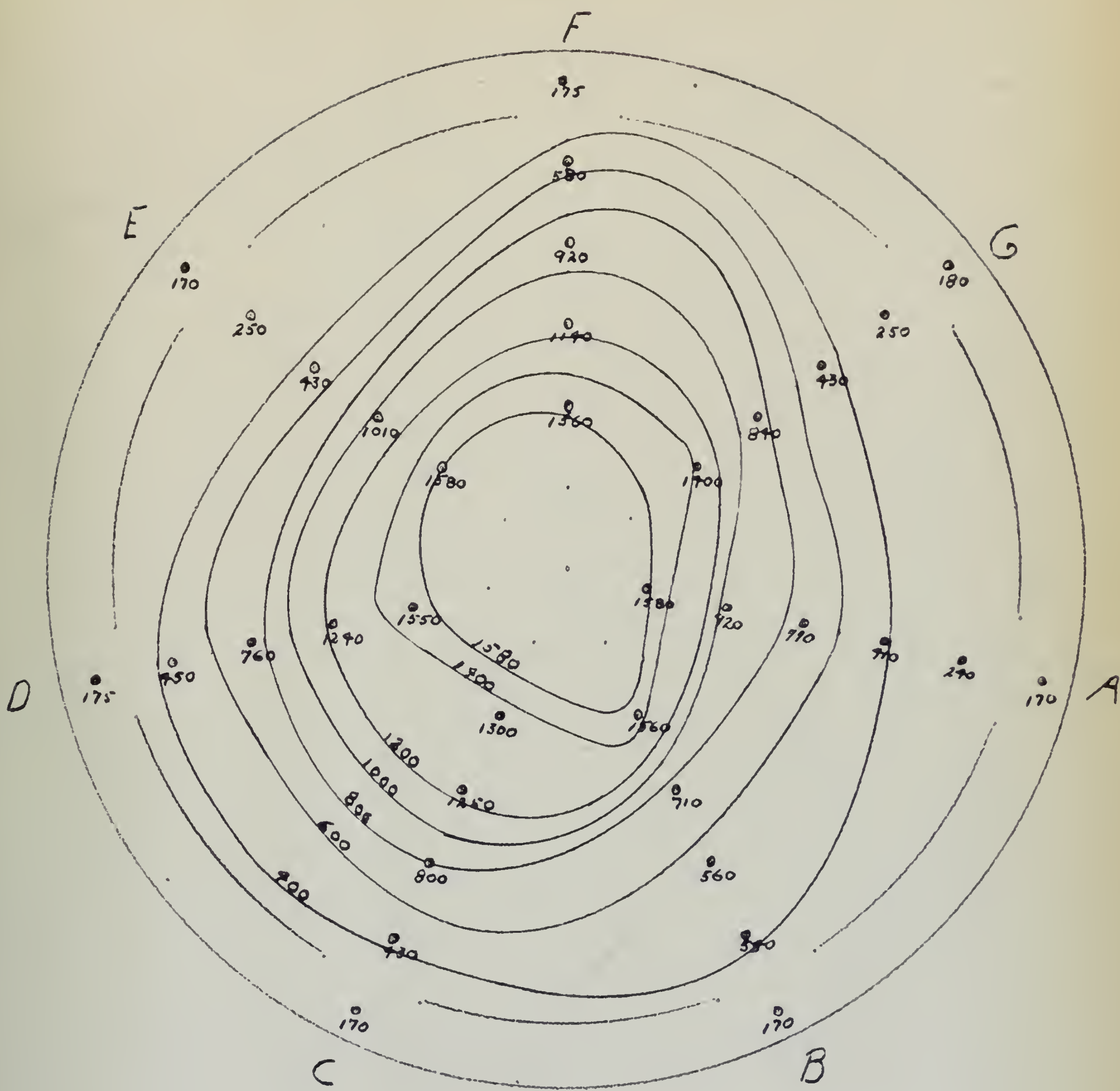
Figure 8




Temperature pattern at station 2. Operating conditions: Fuel-air ratio, .012; altitude, 3900 feet; engine speed, 5400 RPM. All temperatures in °F.

(High altitude blowout condition being approached)

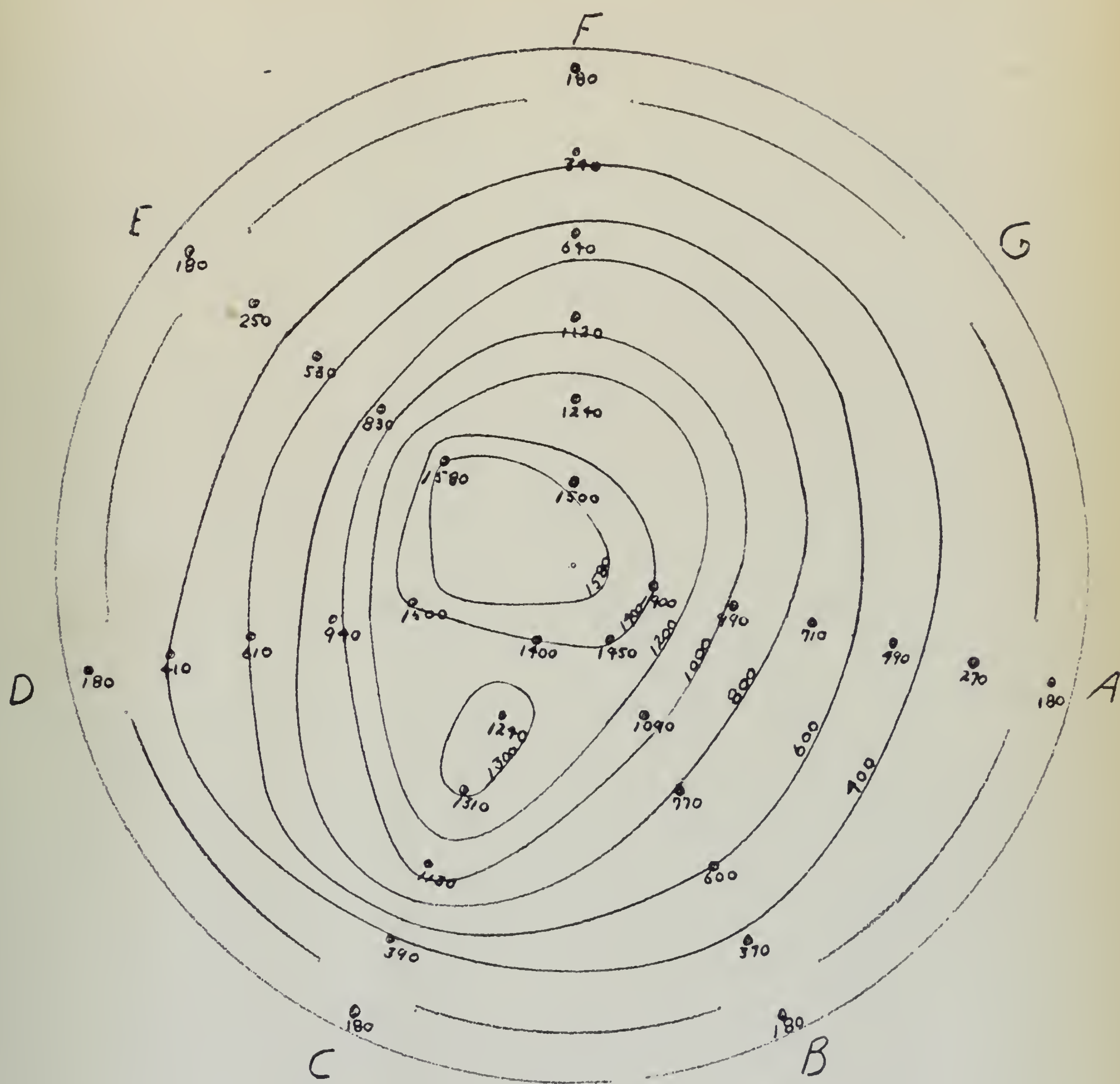
Figure 9




Temperature pattern at station 3. Operating conditions: Fuel-air ratio, .012; altitude, 3900 feet; engine speed, 5400 RPM. All temperatures in $^{o}F$.

(High altitude blowout condition being approached)

Figure 10




Temperature pattern at station 4. Operating conditions: Fuel-air ratio, .012; altitude, 3900 feet; engine speed, 5400 RPM. All temperatures in $^{\circ}F$.

(High altitude blowout condition being approached)

FIG. 11

Temperature profiles along combustion chamber.
Operating conditions: Fuel-air ratio, .012 ;
altitude, 3900 feet ; engine RPM, 5400.

(High altitude blowout condition being approached)

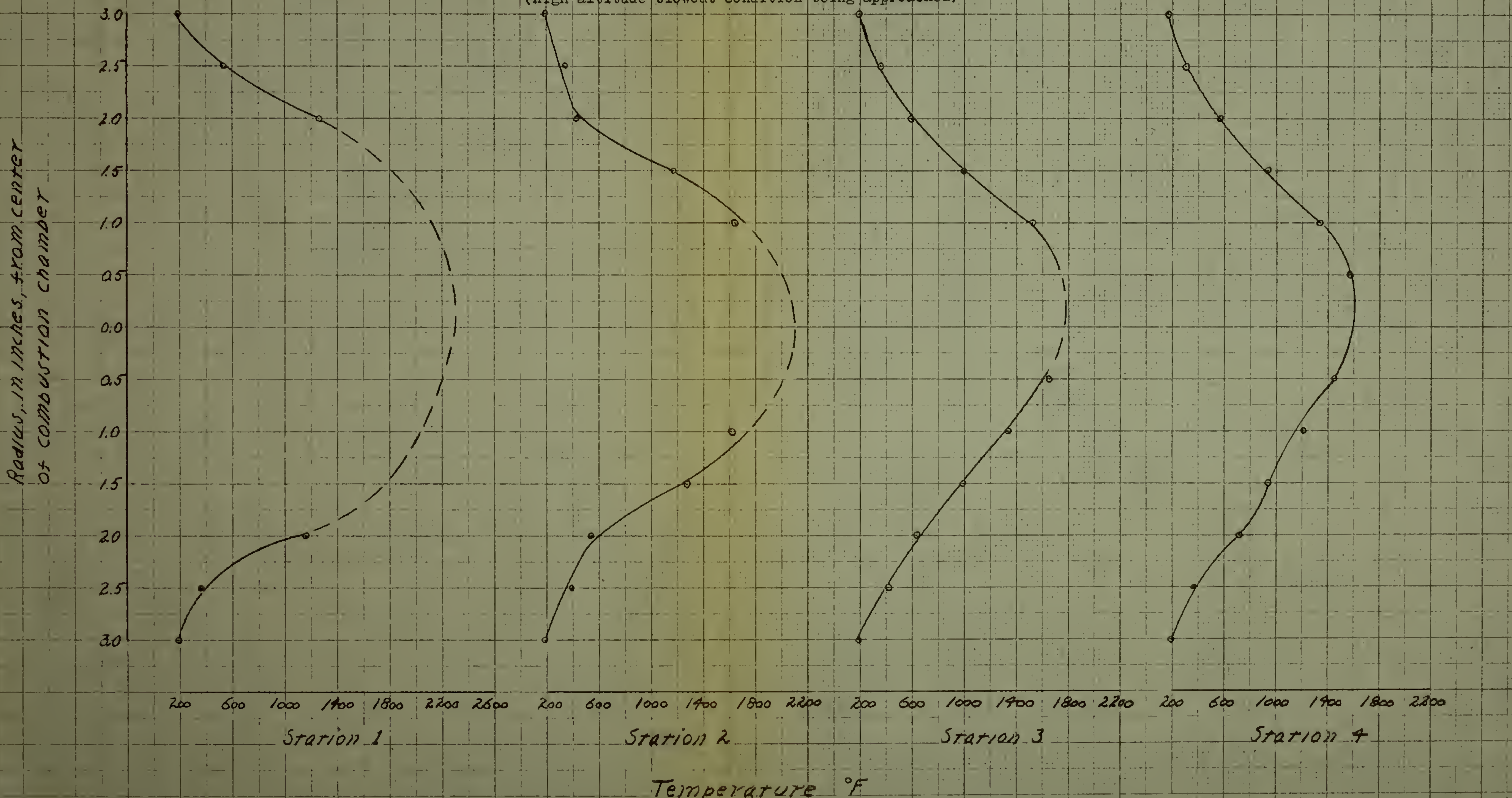
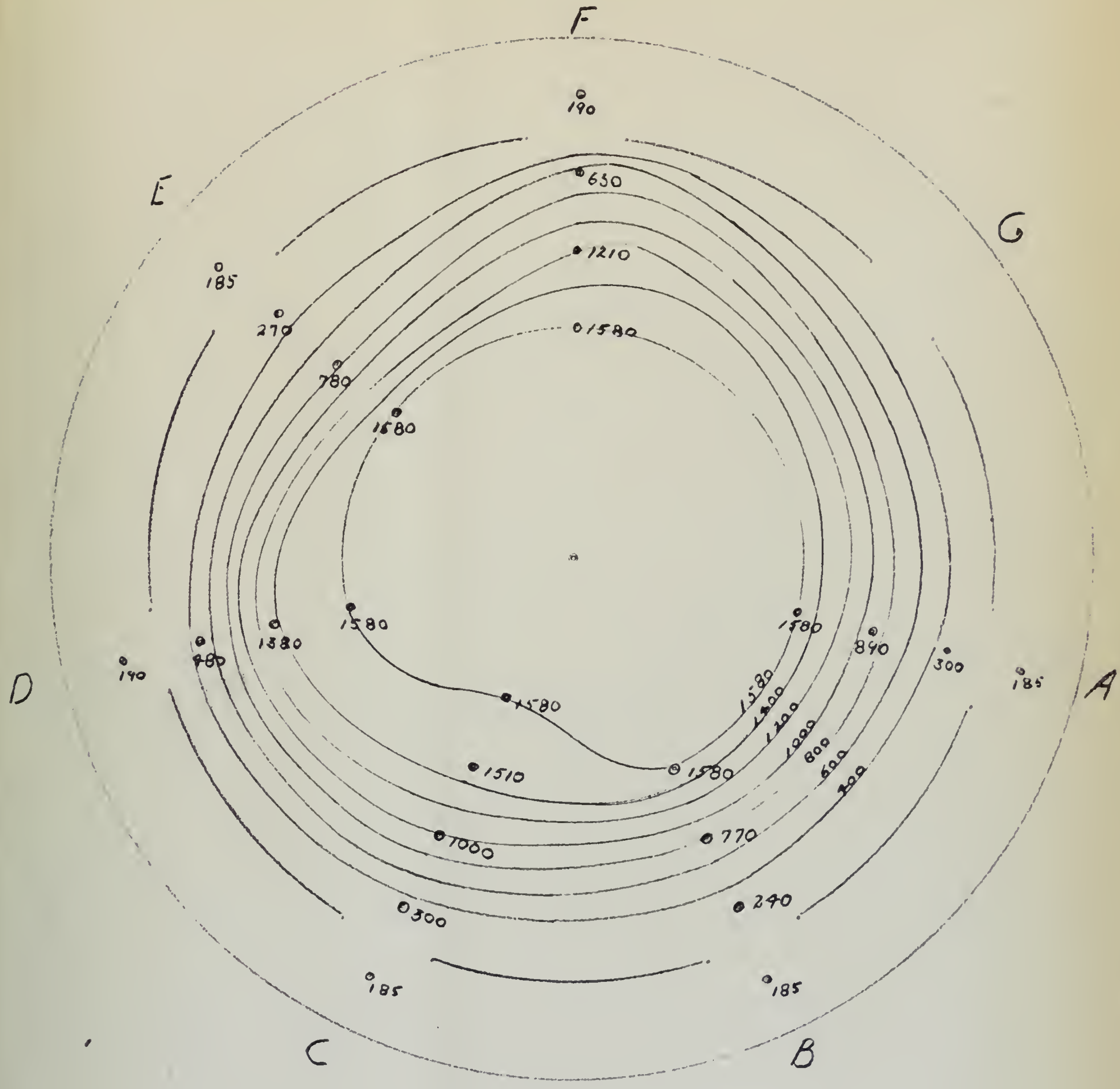


Figure 12




Temperature pattern at station 1. Operating conditions: Fuel-air ratio, .009; altitude, 4000 feet; engine speed, 5350 RPM. All temperatures in °F.

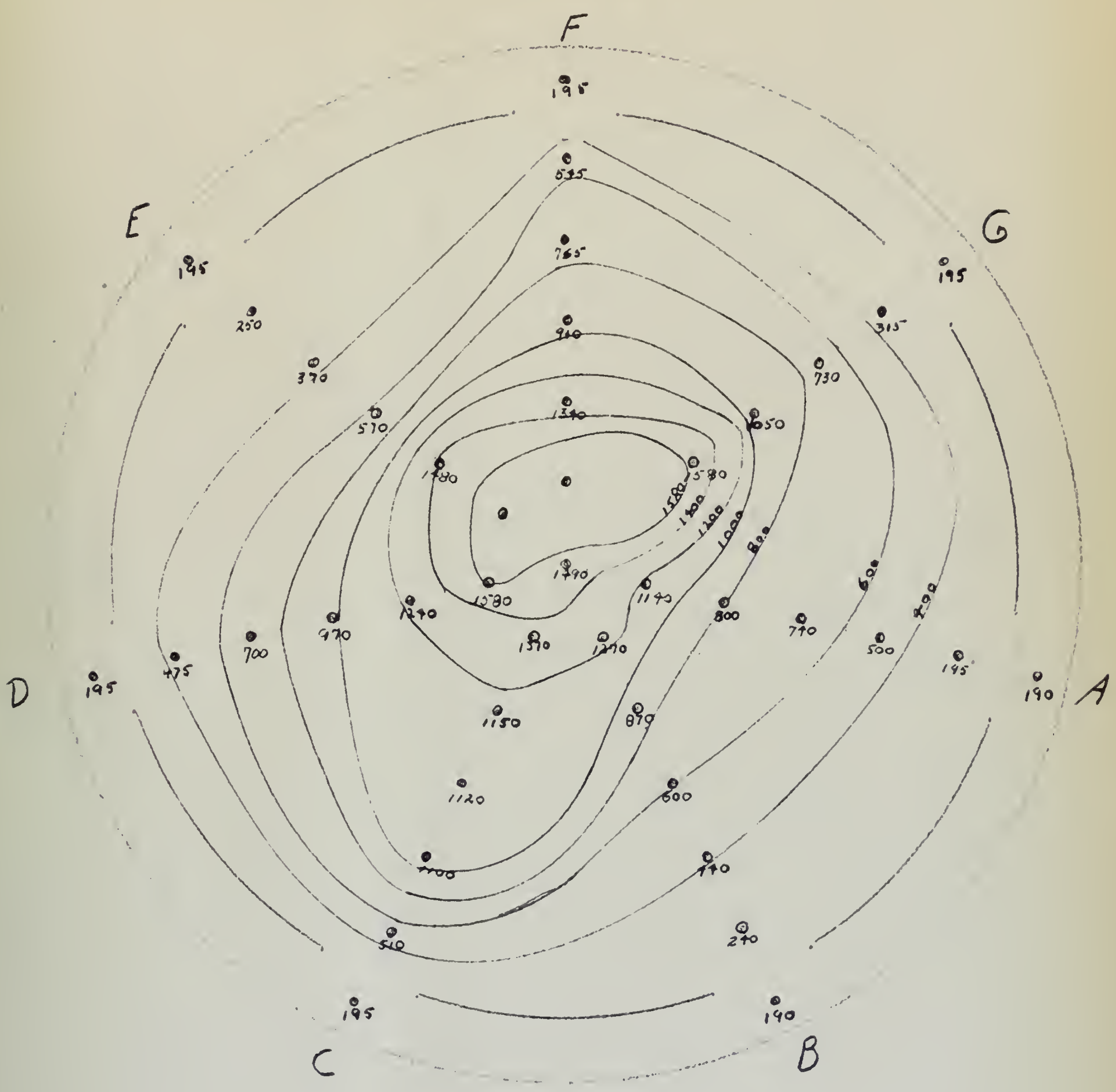
(High altitude blowout condition being approached)

Figure 13


Temperature pattern at station 2. Operating conditions: Fuel-air ratio, .009; altitude, 4000 feet; engine speed, 5350 RPM. All temperatures in $^{o}$F.

(High altitude blowout condition being approached)

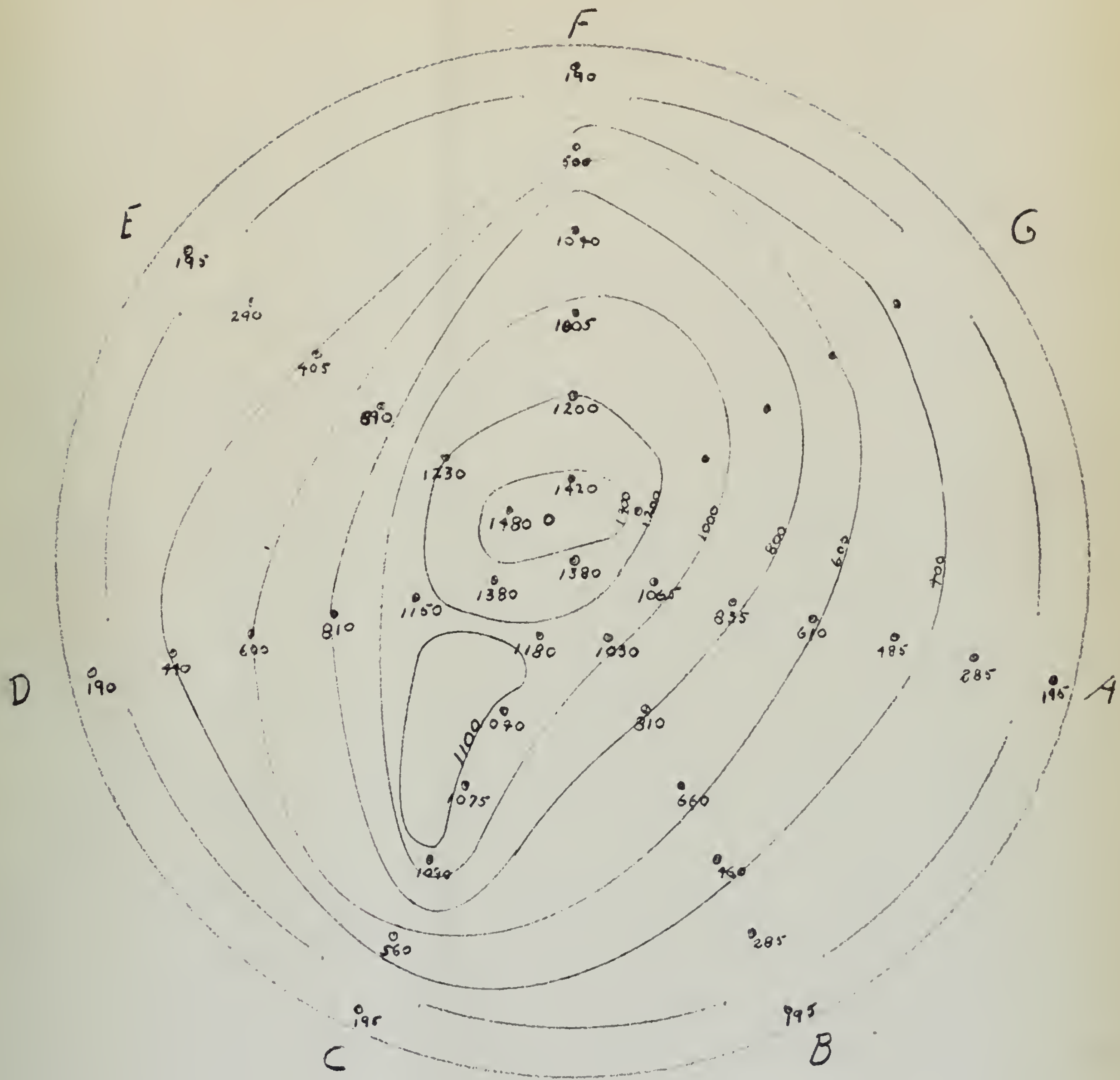
Figure 14




Temperature pattern at station 3. Operating conditions: Fuel-air ratio, .009; altitude, 4000 feet; engine speed, 5350 RPM. All temperatures in °F.

(High altitude blowout condition being approached)

Figure 15

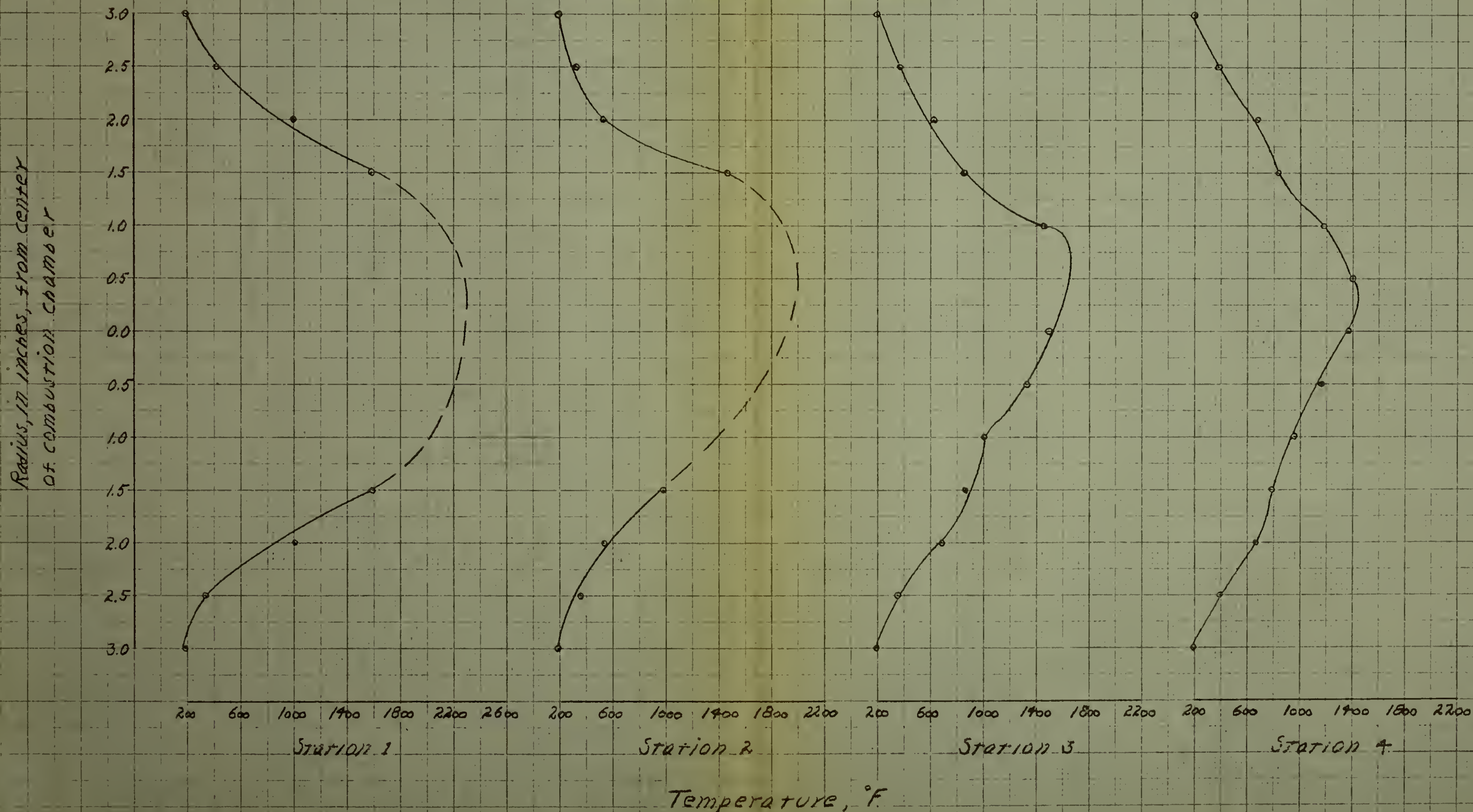



Temperature pattern at station 4. Operating conditions: Fuel air ratio, .009; altitude, 4000 feet; engine speed, 5350 RPM. All temperatures in °F.

(High altitude blowout condition being approached)

FIG. 16

Temperature profiles along combustion chamber
Operating conditions: Fuel-air ratio, .009 ;
altitude, 4000 feet ; engine RPM, 5350.
(High altitude blowout condition being approached)



# APPENDIX A

## SAMPLE CALCULATIONS

We have, for a square edged orifice:

$$w = .668\ A_2\ K \sqrt{C\ (\Delta P)} \qquad \text{from Ref. 4}$$

where:

$w$ = air flow, lb/sec

$A_2$ = throat area of orifice plate, sq. in.

$K$ = flow coefficient (coefficient at discharge with approach factor included)

$C$ = specific weight, lb/cu.ft.

$\Delta P$ = differential pressure across orifice, lb/sq.in.

For the orifice used in this test:

$K = .7$ Ref. 4

$A_2 = 38.5$ sq. in.

And the above formula reduces to

$$w = 2.52 \sqrt{\frac{Pb(\Delta hw)}{To}}$$

where:

$Pb$ = barometer reading, in. Hg.

$\Delta hw$ = differential pressure across orifice, in. H2O

$To$ = inlet temperature to orifice

$w$ = airflow lb/sec

From Table I

$Pb = 29.29$ in. Hg.

$\Delta hw = 14.8$ in. H2O

$To = 95^{\circ}$ F $= 555^{\circ}$ Fabs

Substituting

$$w = 2.52 \sqrt{\frac{29.29\ (14.8)}{555}}$$

$w = 2.225$ lb/sec

or

$w = 8000$ lb/hr

From Table I

Fuel flow, $W_f = 97$ lb/hr

then

$$\text{Fuel-air ratio} = \frac{97}{8000} = .012$$

From Ref. 5 at an air-flow of 8000 lb/hr

Engine speed = 5400 RPM

Total burner inlet pressure
at standard sea level conditions = 44 in. Hg. abs.

Therefore:

$$\text{Compression ratio} = \frac{44.0}{29.92} = 1.47$$

From Table I

Actual total burner inlet pressure,

$Po = 38.20$ in. Hg. abs.

Then

$$\text{Simulated atmospheric pressure} = \frac{38.29}{1.47} =$$

26.0 in. Hg.

And from Ref. 8 at a standard atmosphere pressure of 26.0 in.Hg.

Altitude = 3900 feet

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